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MODEL INVESTIGATION OF WATER LANDINGS OF A WINGED REENTRY

CONFIGURATION HAVING OUTBOARD FOLDING WING PANELS

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MODEL INVESTIGATION OF WATER LANDINGS OF A WINGED REENTRY

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SUMMARY

An investigation has been made to determine the water-landing char-
acteristics of a winged reentry configuration. The all-wing configu-
ration had a delta wing with a leading-edge sweep of 63°, extendable
outboard wing panels, small retractable hydro-skis, and a tail skid.

Smooth-water landings were made over a range of landing angle of
attack from 7° to 16°. In addition, landings were made with yaw and
roll. A few landings were made in waves.

The hydrodynamic longitudinal and lateral stability were good at
all landing conditions investigated. The landing run was between 300
and 400 feet. Maximum normal and longitudinal accelerations occurred
during the first impact of the hydro-skis and were approximately
$2\frac{1}{2}$g and 2g, respectively. The accelerations during landings in small
waves were approximately twice as great as those in smooth water. The
upper surface of the model was essentially clear of spray for all landing
conditions, although heavy spray from the hydro-skis struck the under-
surface of the wing.

INTRODUCTION

Among the many operational problems associated with manned vehicles
in orbit are those of landing and recovery following the landing. One
type of manned vehicle being considered is the winged vehicle. A rela-
tively high-aspect-ratio glider vehicle employing the concept of refer-
ence 1 has as an objective an extended glide range after reentry and con-
trolled landing characteristics. The low-speed aerodynamic characteristics
of the vehicle, when combined with a suitable hydrodynamic gear, provide
the possibility of water landings as an operating concept.

*Title, Unclassified.

Winged vehicles with water-landing capabilities would have a large choice of landing areas and thus freedom in choice of reentry glide path and landing-approach maneuvers. The winged vehicle is capable of extended range after reentry and the selection of the water-landing site could be determined during the glide to avoid extreme wave or weather conditions.

The water-landing characteristics of a winged reentry configuration equipped with a hydro-ski gear have been investigated briefly by dynamic model tests. The configuration had a delta wing with a leading-edge sweep of 63° and extendable outboard wing panels. The fuselage was mounted on the upper surface of the wing. The water-landing gears considered were limited to those which would retract to a position above the wing without interrupting the wing lower surface, which serves as a heat shield upon reentry.

The water-landing impacts and behavior of several arrangements meeting this requirement were determined by free-body landings from the Langley tank monorail. (See ref. 2.) Landings were made in smooth and disturbed water over a range of landing attitudes. The gear determined is not necessarily the optimum gear but proved to be satisfactory for the conditions investigated.

SYMBOLS

b	hydro-ski beam, ft
C_{Δ_0}	gross-load coefficient, Δ_0 / wb^3
w	specific weight of water (63.3 lb/cu ft for these tests)
Δ_0	gross load per ski, lb
α	angle of attack, angle between fuselage base line and horizontal, deg
δ_e	elevator deflection referred to base line, positive when trailing edge is down, deg
C_L	lift coefficient, $\dfrac{\text{Lift}}{qS}$
C_m	pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qS\bar{c}}$

g   acceleration due to gravity, 32.2 ft/sec^2

q   dynamic pressure, lb/sq ft

S   wing area, sq ft

$\bar{c}$ mean aerodynamic chord of wing

PRELIMINARY HYDRODYNAMIC CONSIDERATIONS

Preliminary consideration was given to several water-landing-gear configurations in order to select the most promising for further evaluation. Consideration was given to both twin and single main hydro-ski arrangements, with the requirement that the hydro-ski would not interrupt the heat shield lower surface of the wing. Consideration also was given to the size, location, angle of incidence, and the vertical clearance provided by the landing gear.

A twin hydro-ski gear could be located longitudinally near the center of gravity, pivot about a point on the wing upper surface, and retract to a position above the wing. A single-ski configuration would require a more forward location to permit retraction above the wing. The twin main gear would induce less motion in pitch due to its reduced moment arm over that which would result with a single forward-mounted hydro-ski. For both hydro-ski arrangements, a skid located rearward would reduce bottom impacts and provide spray clearances.

Observations of the preliminary tests indicated that it was desirable to increase the initial incidence of the hydro-skis and skid by lowering their trailing edges and thus provide greater clearances and increased lift. The additional lift was not needed so the area of the ski was reduced by decreasing the beam. By reducing the area in this manner, a greater ski length was available for penetration than would have been if the area had been reduced by cutting the length. Narrow beam hydro-skis effecting a high beam loading have been shown to reduce landing impacts (ref. 3) and the effects of incidence and area upon the lift of the basic planing surfaces for various length-beam ratios have been studied (ref. 4).

The gear length and vertical clearances were kept to the minimum so that the initial impact loads on the undersurface of the wing would be limited in the size of wave investigated. More vertical clearances would be desirable to reduce the loads produced by the hydro-ski roach and spray or for landings in larger waves.

From the results of the preliminary evaluation, a gear was chosen having two hydro-skis near the center of gravity and a skid aft, as shown in figure 1. The (full-size) hydro-skis were 56 inches long, 8 inches wide, and the triangular skid was 18 inches wide and 16 inches long.

DESCRIPTION OF MODEL

A three-view drawing of the configuration is shown in figure 1 and the pertinent characteristics and dimensions of the full-size vehicle are given in table I. Photographs of the 1/8-size dynamic model used for the investigation are shown in figures 2 and 3. The model had a wing span of 3.4 feet and a length of 2.8 feet. The center of gravity was located at $0.36\bar{c}$ and 2.1 inches above the base line. The model was balanced about the center of gravity to a weight corresponding to 3,600 pounds full size. The moments of inertia as determined experimentally are given in table I.

The model was constructed of hollowed out balsa covered with silk. The hydro-skis were made of mahogany 1/4 inch thick and the rear skid was made of sheet brass 1/16 inch thick. The skis and skid were rigidly attached to the model.

The outboard wing panels, which were fixed in the extended position of the landing configuration, were equipped with leading-edge slots. The slots were used to improve the flow due to the leading-edge sweep of the inboard panel. The elevators could be fixed at angles from 20° to -20°.

APPARATUS AND PROCEDURE

The apparatus and procedure used were similar to those used for NASA ditching-model investigations. The monorail facility and the test procedure are described in reference 2.

The elevator settings for trim and approximate flying speeds were obtained from aerodynamic tests conducted with the model on the Langley tank no. 1 towing carriage. In these tests the lift and pitching moment were determined by means of an electrical strain-gage balance located inside the model, with the trailing edge of the model 22 inches above the free water surface. During the aerodynamic tests the best size and location of the leading-edge slots also were determined. Landings were made over a range of launching angle of attack from 7° to 16°. Landings also were made with 5° of yaw at a launching trim of 9° and with 5° of roll at the same trim.

In the catapult tests the model was positioned on the launching apparatus as shown in figure 4 and launched at minimum flying speed from a height of $2\frac{1}{2}$ inches above the water surface. The elevators were set for trimmed flight at the launching angle and the model approximately maintained this trim until contact.

The hydrodynamic data obtained were in the form of visual observations, motion-picture film, and records of the vertical and longitudinal accelerations during landing impacts. The accelerations were measured by two strain-gage-type accelerometers located near the center of gravity of the model (fig. 5). The accelerometers had a natural frequency of approximately 160 cycles per second and were damped to about 70 percent of critical damping. The response of the recording equipment was flat to 90 cycles. In the static condition the accelerometers read zero. A trailing overhead cable was used to transmit the accelerometer signal to an oscillograph recorder near the catapult. Check tests indicated the trailing cable had a negligible effect upon the behavior of the model.

RESULTS AND DISCUSSION

A short motion-picture film supplement of the water landings has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper on the page preceding the abstract and index page. All data presented have been converted to full-size values.

Aerodynamics

With a center-of-gravity location of $0.42\bar{c}$ the model was very unstable in pitch over most of the angle-of-attack range. Therefore, the center of gravity was moved forward to $0.36\bar{c}$ to provide a wider range of stable angle of attack. Very brief aerodynamic data as obtained from tank tests are plotted against angle of attack in figure 6, the center of gravity being located at $0.36\bar{c}$. At high angles of attack, the elevators were set to avoid pitchup in the short period of flight before initial water contact.

Landings in Smooth Water

Observations of landings with the twin hydro-skis but without the rear skid indicated that the wide planing area presented by the wing trailing edge resulted in large pitching oscillations and impact forces. The single skid rearward took the loads off the wing and considerably reduced the motions in pitch.

At a landing attitude greater than 10°, the rear skid contacted the water first. The model rotated down in pitch about the skid until contact was made by the hydro-skis. For a landing attitude less than 10°, the initial contact was made on the hydro-skis. Attitude at contact had no significant effect upon most of the landing run, since the pitching motions caused by initial contact damped rapidly.

The length of the landing runout decreased with landing speed; it was approximately 400 feet for a landing attitude of 7° and decreased to about 300 feet for a landing attitude of 16°.

No instability was encountered during landings with 5° of yaw or 5° of roll. Upon initial contact the yaw or roll corrected rapidly and the remainder of the landing runout was similar to other landings without yaw or roll.

Accelerometer records obtained for the three launching attitudes are shown in figure 7. The maximum longitudinal and normal accelerations occurred during the first impact of the hydro-skis and the records appeared to be similar for all landing angles. When landing at angles greater than 10°, the initial impact of the skid caused the model to pitch down but did not appear to produce any measurable normal or longitudinal loads.

The maximum normal and longitudinal accelerations obtained for each landing over the range of landing angles are shown in figure 8. The maximum normal accelerations (fig. 8(a)) were approximately $2\frac{1}{2}g$ and the maximum longitudinal accelerations (fig. 8(b)) were approximately $2g$ for most of the landing attitudes.

Landings in Small Waves

Several landings were made at an attitude of 9° (approximately the sternpost angle) directly into irregular waves approximately 8 inches high and 30 feet long.

Position on the wave at initial contact apparently had little effect upon the landing behavior and the motions were similar for repeated landings.

After initial contact, the trim and rise amplitudes remained nearly constant during the landing runout. The length of the landing run in the waves was approximately the same as that in smooth water (300 to 400 feet).

The normal and longitudinal accelerometer traces obtained during a landing in waves are reproduced in figure 9. The initial impact usually gave the maximum normal and longitudinal accelerations, which were followed by a series of lesser accelerations as contact was made with successive waves. The maximum normal and longitudinal accelerations for landings in the 8-inch waves were approximately twice as great as those in smooth water (approximately 5g and 4g, respectively).

Spray Characteristics

Photographs of the spray during a smooth-water landing sequence are shown in figure 10. Detailed observations for all the landing conditions investigated may be made from the motion-picture film. Similar spray characteristics were observed for landings in smooth water and in waves. During all the landings, the fuselage and the upper surface of the wing were essentially clear of spray. Heavy spray from the hydro-skis, however, struck the underside of the wing.

CONCLUDING REMARKS

Water landings of the model of the winged reentry configuration indicated that longitudinal and lateral hydrodynamic stability were good at all landing conditions investigated (angle of attack from 7° to 16°) and the landing runout was between 300 and 400 feet. During landings with 5° of yaw or roll, the model corrected on initial contact and the motions damped rapidly.

The maximum normal and longitudinal accelerations occurred during the first impact of the hydro-skis and were approximately $2\frac{1}{2}g$ and $2g$, respectively, for most of the landing angles. These accelerations during landings in small waves (about 8 inches high full size) were approximately twice as great as those obtained in smooth water.

The fuselage and the upper surface of the wing received very little spray during all the landings, but heavy spray from the hydro-skis struck the undersurface of the wing.

Langley Research Center,
    National Aeronautics and Space Administration,
        Langley Field, Va., June 23, 1959.

REFERENCES

1. Staff of Langley Flight Research Division (Compiled by Donald C. Cheatham): A Concept of a Manned Satellite Reentry Which is Completed With a Glide Landing. NASA TM X-226, 1959.

2. Christopher, Kenneth W.: Effect of Shallow Water on the Hydrodynamic Characteristics of a Flat-Bottom Planing Surface. NACA TN 3642, 1956.

3. Schnitzer, Emanuel: Reduction of Hydrodynamic Impact Loads for Waterborne Aircraft. NACA RM L55E09b, 1955.

4. Weinstein, Irving, and Kapryan, Walter J.: The High-Speed Planing Characteristics of a Rectangular Flat Plate Over a Wide Range of Trim and Wetted Length. NACA TN 2981, 1953.

TABLE I.- PERTINENT CHARACTERISTICS AND DIMENSIONS

OF THE FULL-SIZE VEHICLE

General:

Gross weight, lb 3,600
Wing area, sq ft 263
Wing loading, lb/sq ft 13.7
Moment of inertia -
Roll, slug-ft^2 2,200
Pitch, slug-ft^2. 2,700
Yaw, slug-ft^2 4,300

Wing:

Span, ft 27
Area, sq ft 263
Length, mean aerodynamic chord, ft 12.6

Fuselage:

Length, ft 20
Center of gravity, above fuselage base line, ft 1.4
Distance to center of gravity from forward
perpendicular, ft 11.9

Hydro-ski:

Length, ft 4.7
Beam, ft 0.67
Length-beam ratio 7.0
Total area, sq ft 6.3
Beam-loading coefficient, C_{Δ_0} 95

$\dfrac{\text{Gross weight}}{\text{Ski area}}$, lb/sq ft 571
Incidence, deg 24
Distance of trailing edge below fuselage base line, ft 1.5
Distance of trailing edge behind center of gravity, ft 0.3
Sternpost angle, deg 10

Skid:

Length, ft 1.3
Beam, ft 1.4
Area, sq ft 0.9
Incidence, deg 40
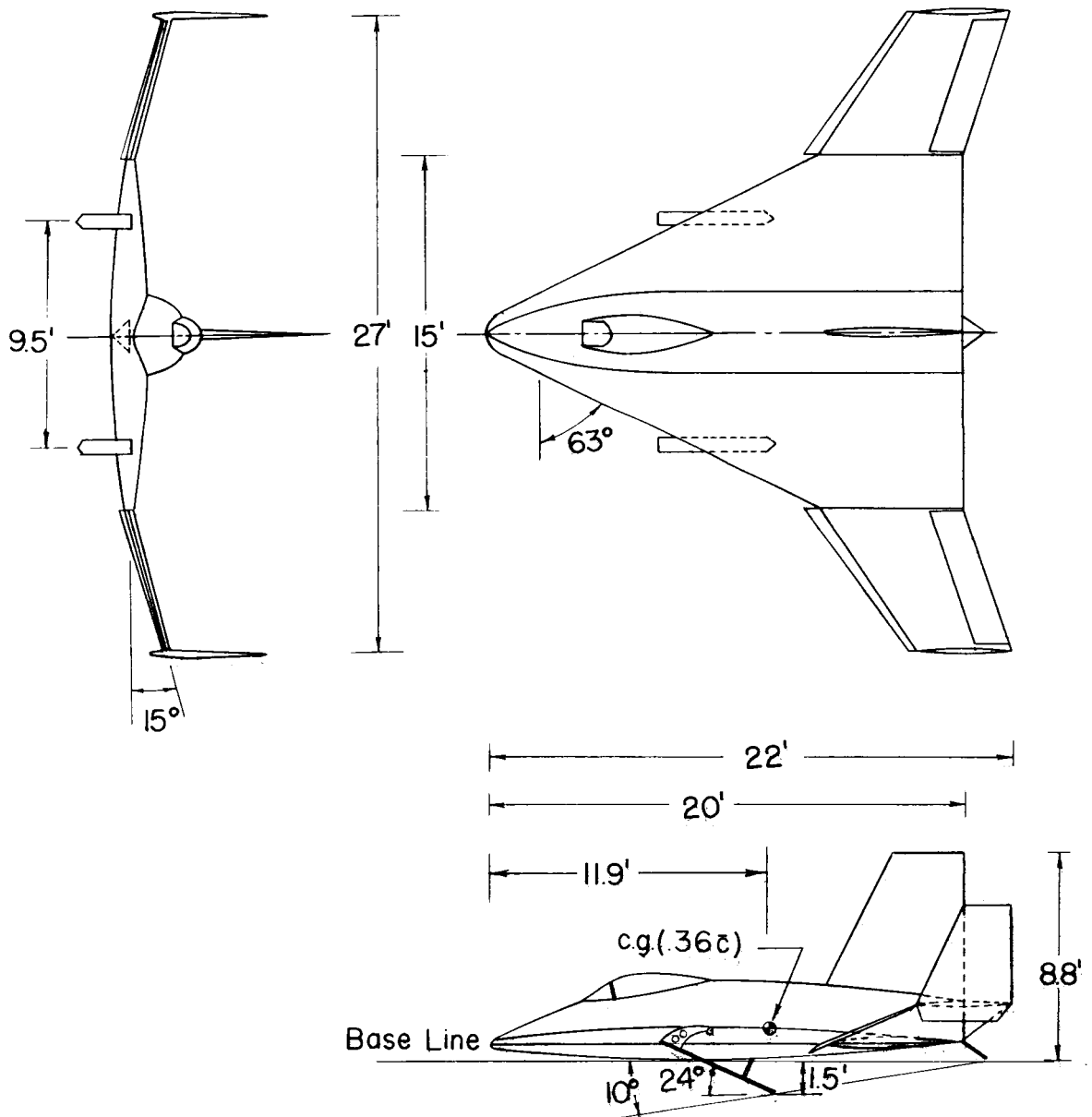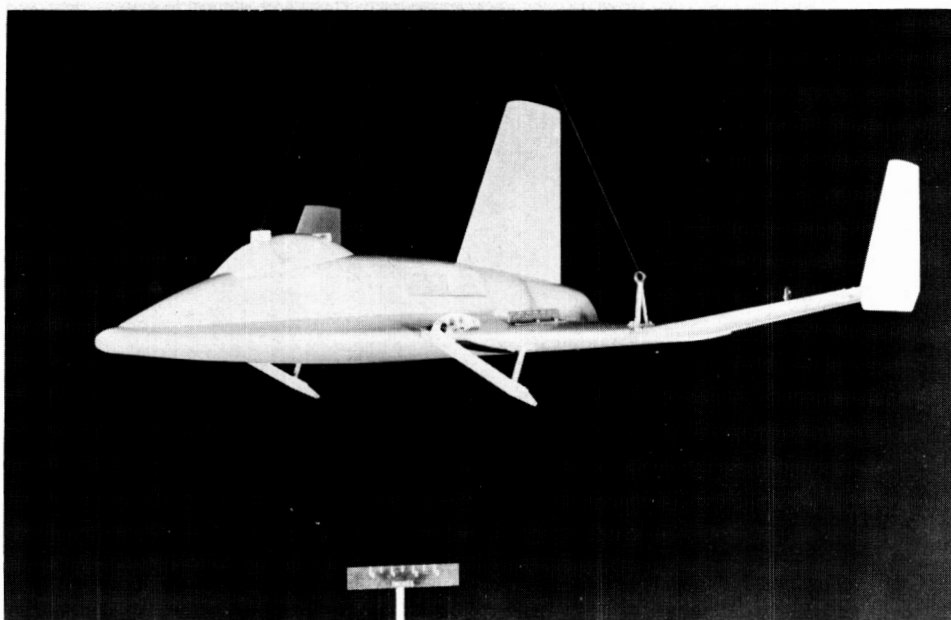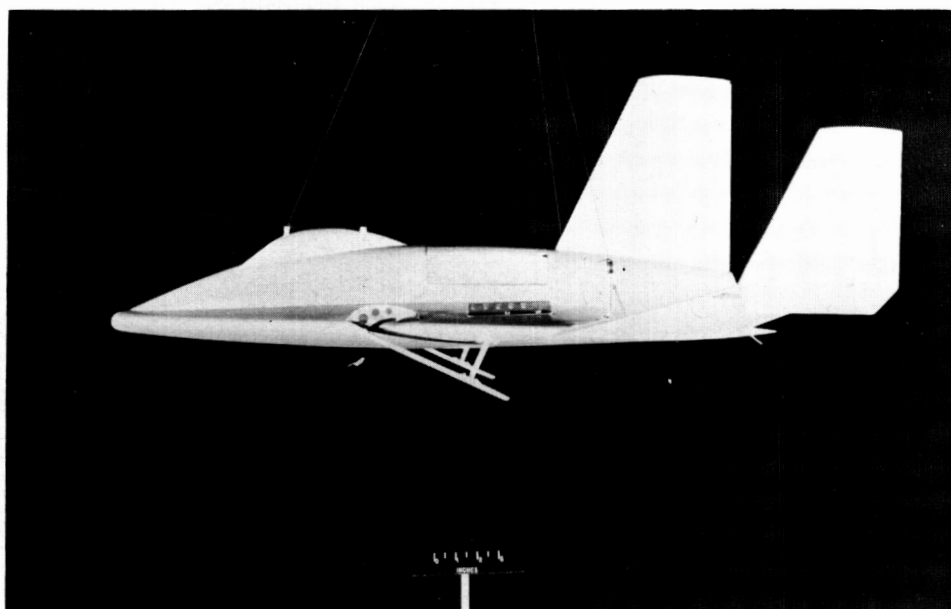
Figure 1.- General arrangement of full-size configuration.

(a) Three-quarter front view.   L-58-3400

(b) Side view.   L-58-3399

Figure 2.- Photographs of $\frac{1}{8}$-size dynamic tank model.
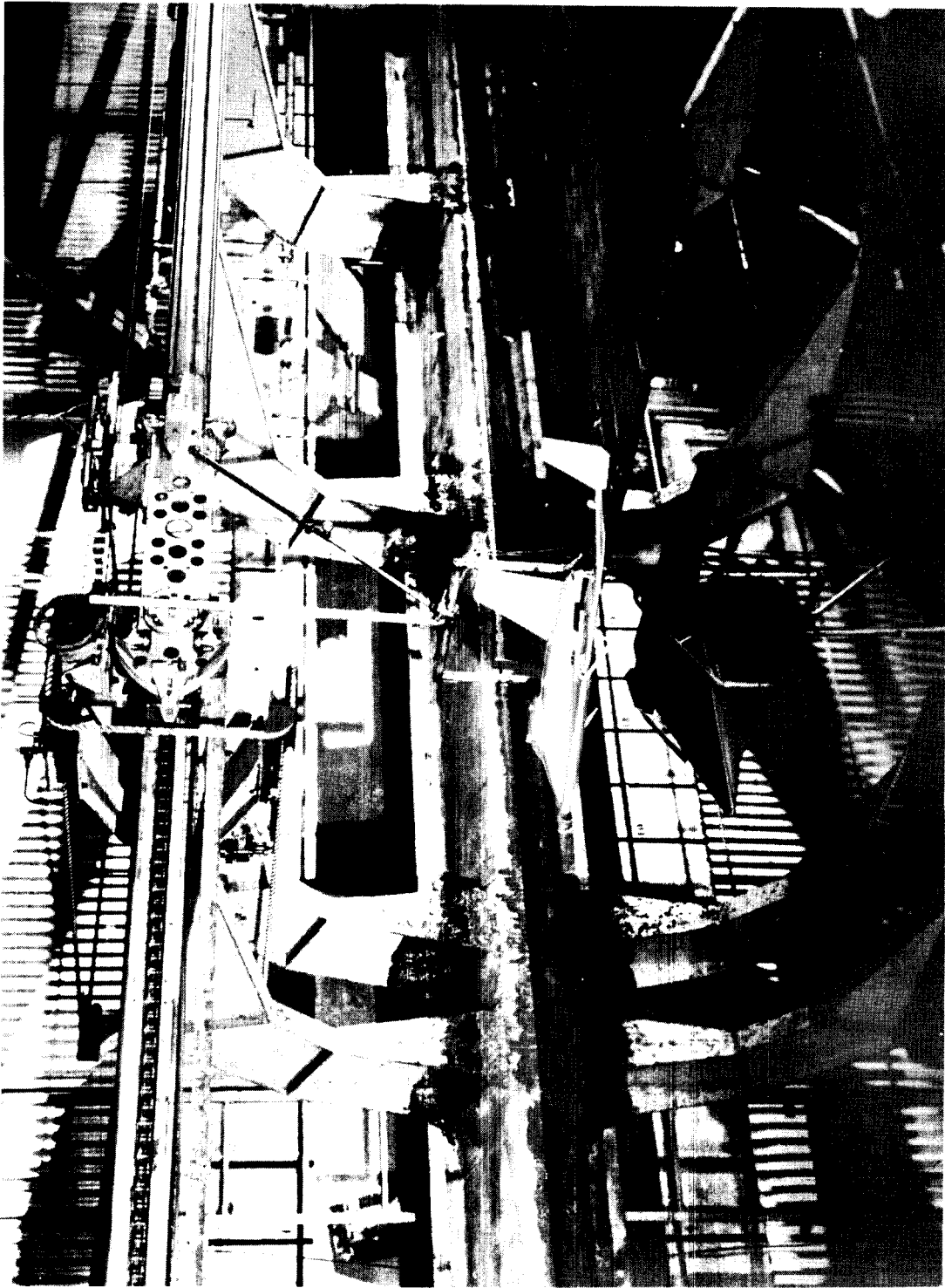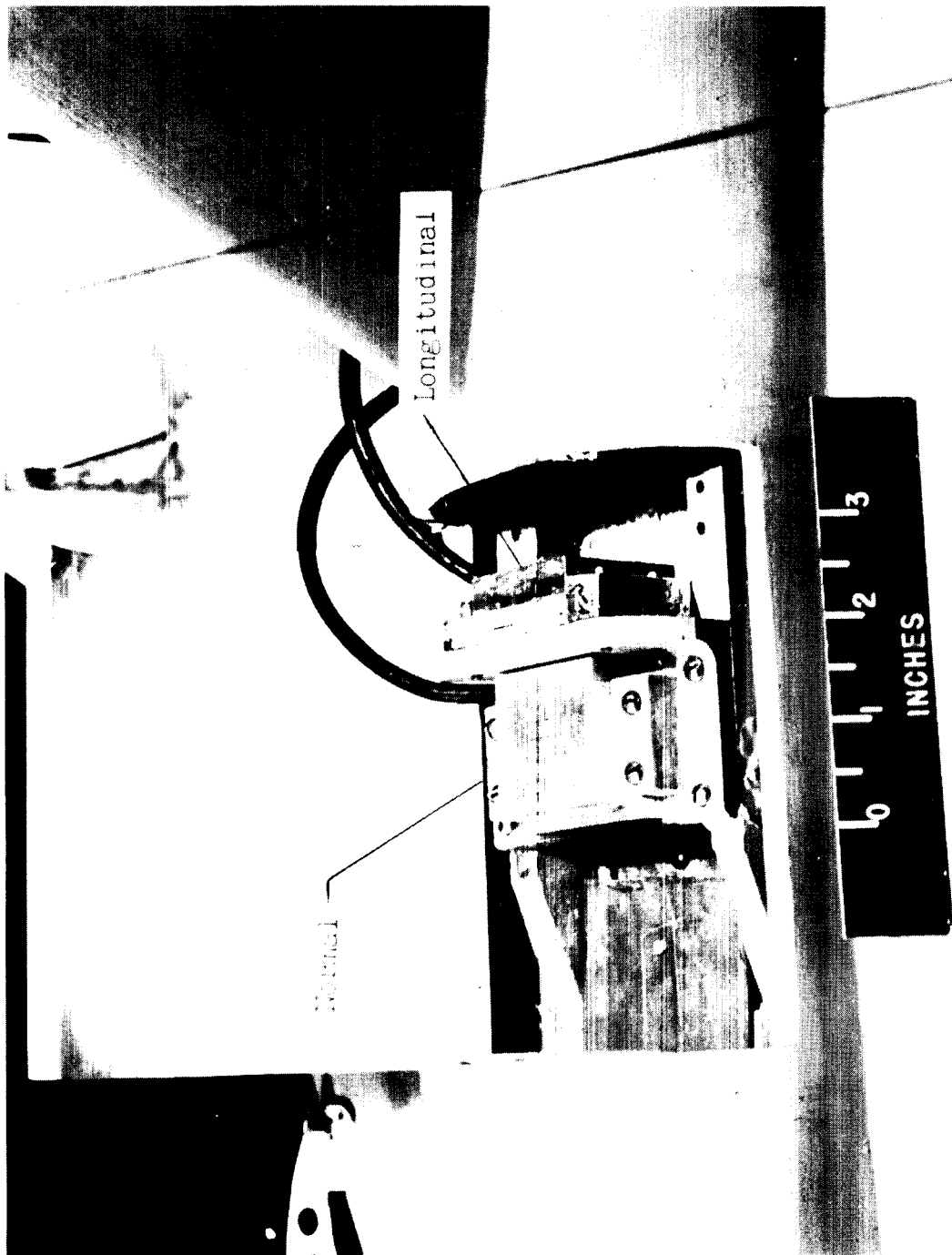
Figure 3.- Model at rest on water.   L-58-3286

Figure 4.- Model on launching apparatus.   L-58-3285

CONFIDENTIAL

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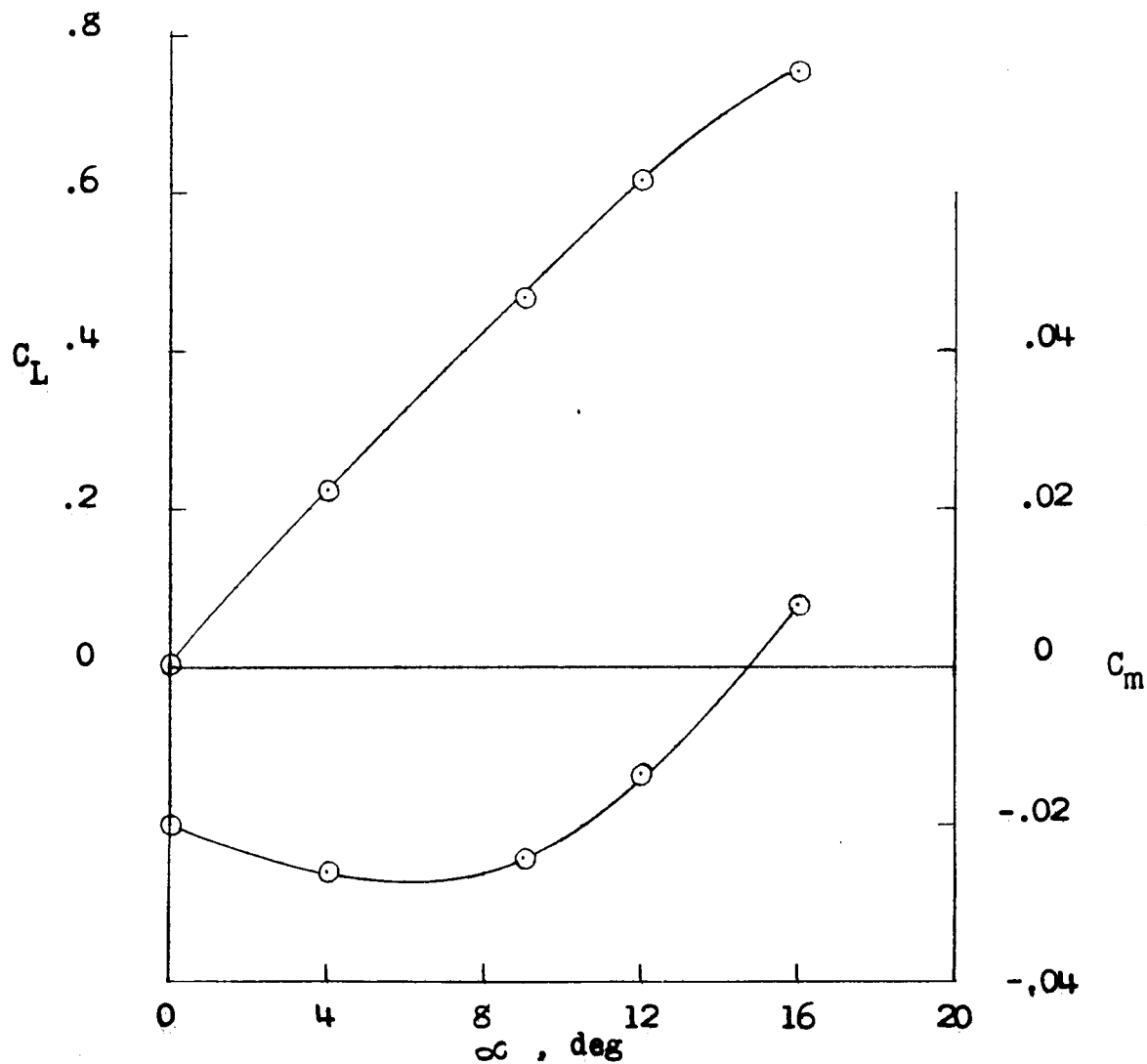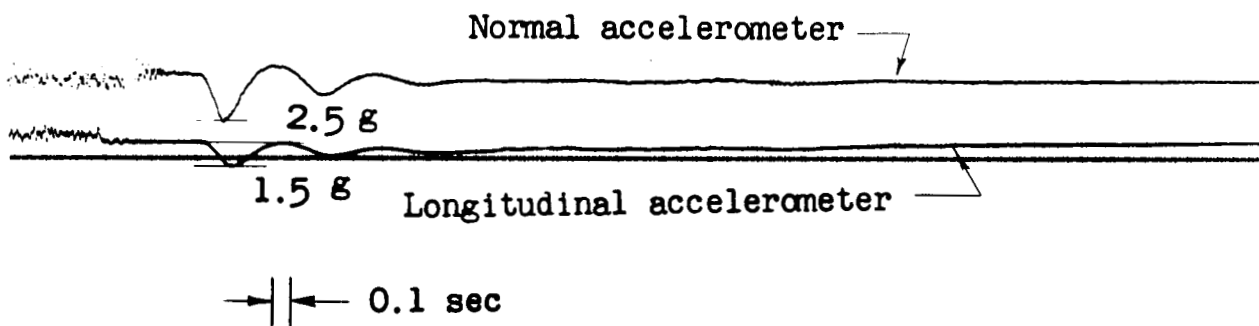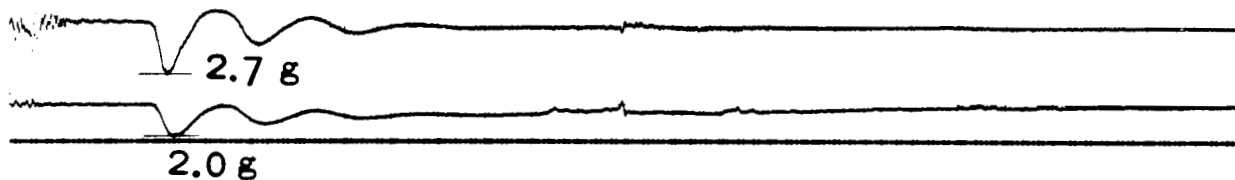Figure 5.- Normal and longitudinal accelerometer installation.

Figure 6.- Aerodynamic lift coefficient and pitching-moment coefficient with wing trailing edge 22 inches above water surface. Center-of-gravity location, $0.36\bar{c}$; $\delta_e = 0^o$.

Normal accelerometer
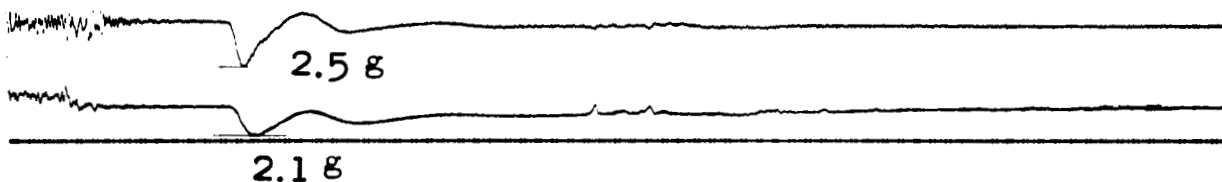
2.5 g

1.5 g   Longitudinal accelerometer

⊢|⊣ 0.1 sec

(a) Launching attitude, 9°; speed, 82 knots.

2.7 g

2.0 g

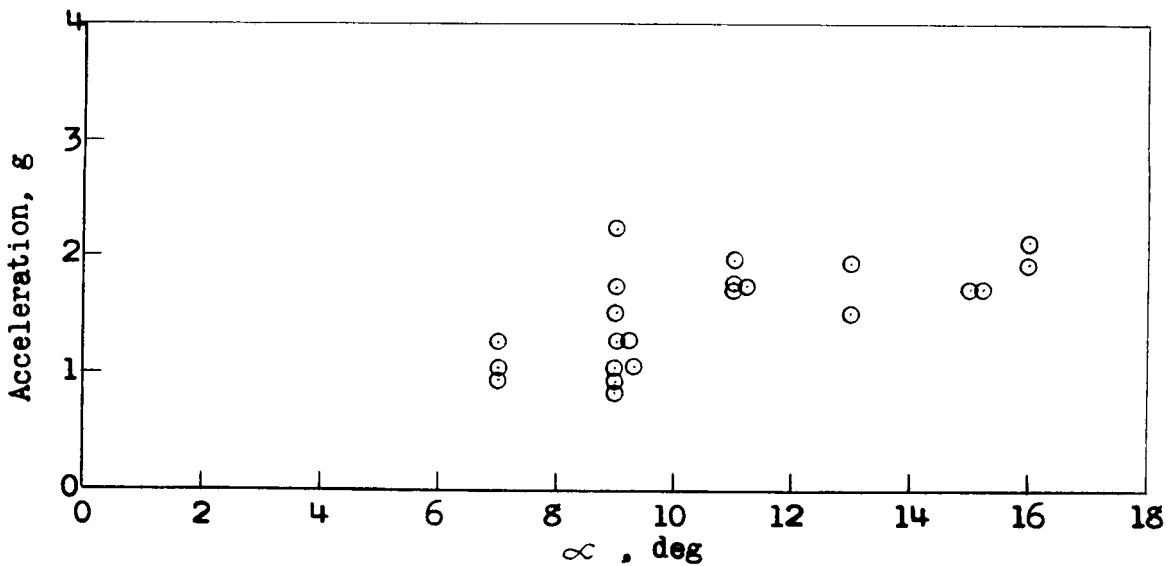(b) Launching attitude, 13°; speed, 70 knots.

2.5 g

2.1 g

(c) Launching attitude, 16°; speed 66 knots.

Figure 7.- Typical accelerometer records obtained during smooth-water
landings for launching trims of 9°, 13°, and 16°. (All values are
full scale.)
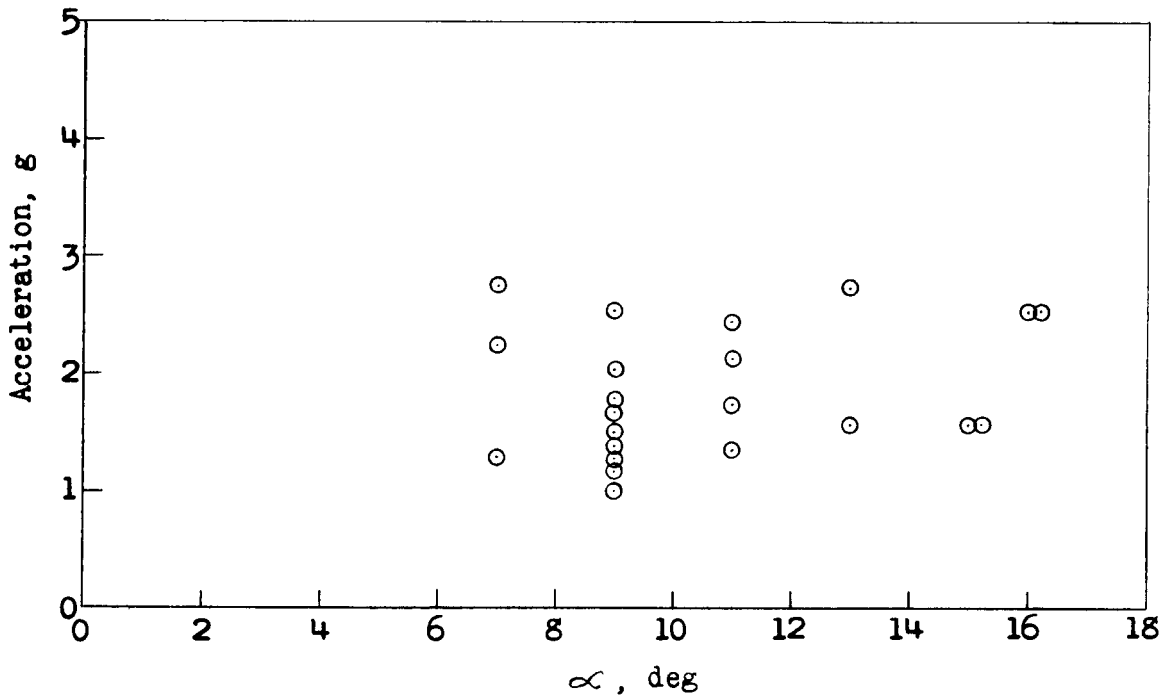
(a) Normal accelerations.

(b) Longitudinal accelerations.

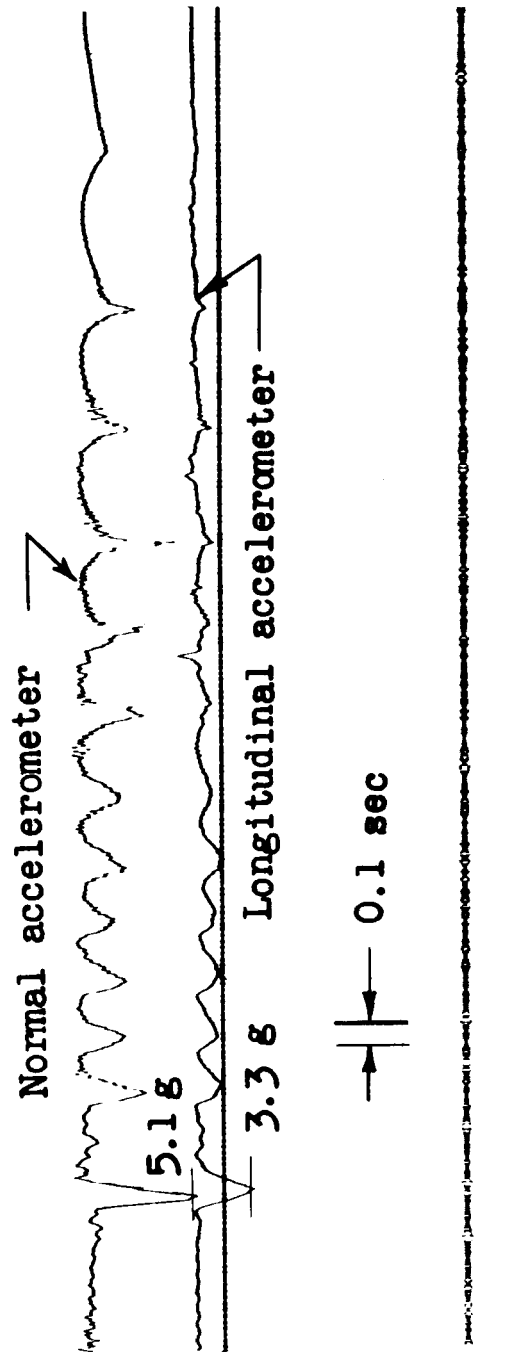Figure 8.- Maximum normal and longitudinal accelerations obtained during smooth-water landings.

Figure 9.- Typical accelerometer record obtained during landing in small waves. Launching trim, 9°; wave height, 8 inches; wave length, 30 feet. (All values are full scale.)

Figure 10.- Spray photographs of model near initial contact during smooth-water landing.

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